Treatment Wetlands Overview

Chapter Highlights

- Wetlands are environmentally sensitive areas that are adapted for variable hydrologic conditions.
- Constructed treatment wetlands are used to treat wastewater by mimicking the processes seen in natural wetlands.
- Constructed treatment wetlands are engineered systems that differ from natural systems.
- Free water surface wetlands operate with a water depth of 3” to 18”.
- Subsurface flow wetlands are designed to maintain the entire depth of the water column within the soil media. In a subsurface flow wetland the water level is not visible at the ground.

What Is A Wetland?

What is a wetland? Definitions vary from Oxford Dictionary’s characterization of wetlands as “swamps and other damp areas of land” to Kadlec and Knights “Wetlands are land areas that are wet during part or all of the year because of their location in the landscape.[1]” For the purposes of this report, we define wetlands as environmentally sensitive areas that can be identified by the following attributes:

Anaerobic refers to the absence of oxygen.

Litter layer is a deposit of partially decomposed organic matter.

Soil Type

Wetland soils are inundated by water or are saturated for extended periods and are characterized by a lack of oxygen. Their soils typically contain a high proportion of organic matter as a result of annual vegetation production. This combination of **anaerobic** conditions and a thick **litter layer** provide ideal conditions for chemical and microbial processes.

Hydrologic Characteristics

Wetlands are characterized by a hydrologic regime that provide periods of inundation and saturation. Important aspects of wetland hydrology include the detention time in the wetland, the water depth, the flow velocity through the wetland and the number of days per year in which the wetland is inundated.

Plant Species

Wetlands are home to a diverse group of plants, including emergent, floating and submerged species. Wetland plants are adapted to survive in saturated conditions. While most plants absorb oxygen through their roots, wetland plants can also absorb oxygen through their stems and leaves and transport it to their roots through specialized root cells.

[1]Robert H. Kadlec & Robert L. Knight: *Treatment Wetlands*, Lewis Publishers, Boca Raton, 1996.

Typical Microorganisms

Wetlands provide ideal conditions for a wide variety of microorganisms. These organisms are the 'workhorses' in the wetland treatment processes.

The construction of wetlands to treat wastewater is based on the chemical, biological, and physical processes that occur in natural wetlands. Because the soil or substrate in a wetland is commonly saturated, chemicals that enter the wetland in an oxidized state undergo transformations when exposed to the reduced conditions of the saturated soils. Biological activity in the **biofilm** that attaches to wetland soil and plants accounts for much of the dissemination and transformation of pollutants. Physical entrapment and sedimentation of wastewater solids are also key processes to remove pollutants. As wastewater treatment professionals recognized these processes in natural wetlands, they began to construct treatment wetlands to accomplish the same purposes.

Biofilm is a slime layer where microorganisms live. **Sedimentation** is a physical process by which solids settle to the bottom of a liquid.

Comparison of Natural and Treatment Wetlands

Although constructed treatment wetlands mimic many of the conditions seen in the natural wetland, there are significant differences. The primary goal of a treatment wetland is to improve the quality of the water flowing through it to a level that will meet discharge permit requirements. Since it is usually desirable to accomplish these requirements with minimal cost, energy and maintenance input, modifications to the natural system are necessary. Significant differences between constructed wetlands and natural wetlands are discussed below.

Comparison of Wetlands

Natural Wetland

- Accumulated organic matter
- Natural water source
- Biodiversity
- Microorganisms determined by existing environment

Constructed Wetland

- No or limited organic layer
- Piped water source
- Less biodiversity
- Microorganisms determined by type of wastewater

Soil Type

Some natural wetlands have soils that have formed as the result of many years (often 1000's of years) of accumulated organic matter. These rich soils are home to a wide variety of microorganisms. Soils used in constructed wetlands often lack organic matter and are not well developed. Some constructed wetlands are designed with specific soil properties to maintain a certain flow rate, or to prevent percolation to the groundwater.

Hydrologic Characteristics

Treatment wetlands are generally fed by a piped water source. Since these wetlands are often constructed in upland areas outside of drainages or natural depressions, they do not usually intercept natural surface water drainage during storm or flood events. Because of this their function in floodwater and sediment retention is different from a natural wetland. In addition, unlike natural wetlands, treatment wetlands are often lined with clay or plastic. This prevents groundwater discharge and recharge into the wetland.

Plant Species

Constructed wetlands often support a less diverse plant community than natural wetlands. Constructed wetlands are typically seeded or planted. Since all the plants are usually started at the same time, it is easier for the dominant species to overtake the wetland area before the less dominant species can become established. Since the hydrology in a constructed wetland is generally not as variable as what is experienced in a natural system, conditions in the constructed wetland will always favor a certain plant species.

Typical Microorganisms

The type of wastewater being treated determines the microorganisms that will flourish in the constructed wetland. Typically, the wastewater already contains a community of microorganisms before it is introduced into the wetland. Constructed wetlands are designed to provide an ideal habitat for microbial communities to breakdown key pollutants. Temperature and oxygen levels in wetlands play important roles in microbial processes. Constructed wetlands may be designed so that certain temperatures and dissolved oxygen parameters are maintained.

Common Design Methods

- Historical Data
- Attached growth models
- Areal & Volumetric Loading

Design Methods

The first step in designing a wetland system is to determine the required wetland size needed to reach treatment goals. Since available land is frequently a limiting factor, the area required by wetland systems often establishes the viability of using this option. Currently, there is not a universally accepted design process for sizing wetlands. The following paragraphs describe the most common methods used to size a constructed treatment wetland.

Historical Data

Empirical data collected from pilot scale and fully operational treatment wetlands are used to develop relationships between treatment goals and size requirements. Data stored in the NADB has been used to a limited degree to predict wetland performance. Relationships derived from empirical data may be useful if the designer has reliable data from a wetland with similar operating and climatic characteristics.

Attached Growth Models

This approach makes the assumption that first-order plug flow models used to design traditional wastewater treatment systems can be used to describe wetland treatment processes. This approach also assumes that the reaction of wastewater components can be described by first order reaction kinetics. The general relationship for first-order plug flow models is:

$$C_t = C_o \exp^{-kt}$$

Where: Ct = effluent pollutant concentration at t = t

t = mean hydraulic detention time

k = apparent first-order rate constant

Co = initial pollutant concentration (t = 0).

The apparent first-order rate constant can be adjusted by the following formula to correspond with a desired temperature:

$$k = k_{20}\Theta^{(T-20)}$$

Where: k = apparent first-order reaction rate constant at T degrees (°C)

K20 = apparent first order reaction rate constant at 20°C

Θ = empirical temperature coefficient, and

T = desired temperature (°C).

Several derivations of the plug-flow model have been developed to incorporate different approaches for defining the reaction coefficient and mean hydraulic detention time.

Areal and Volumetric Loading

Relationships are developed between the volume of water or mass of pollutant load introduced to the system to the surface area of the wetland. Areal loading rates can provide an expected effluent concentration for a particular constituent based on performance data from other similar systems. A limitation of this method is the invalid assumption that the influent is applied uniformly over the land area. Typically, wastewater is applied at the head of the wetland cell and allowed to flow across and/or through the wetland structure to the collection pipe at the end of the cell. Additional simplifications in this design method do not account for the water depth or temperature in the wetland.

Design Considerations

Wetland size requirements are determined by using one of the design methods discussed above. Generally, the treatment level needed to satisfy discharge permit requirements will be the driving factor in determining the limiting pollutant for which the wetland should be designed. Some pollutants typically monitored are discussed below.

Biological Oxygen Demand (BOD)

BOD is a measure of the amount of oxygen that a wastewater stream will consume during biological decomposition processes. The amount of oxygen that a wastewater sample will consume in 5 days (BOD_5) is the most commonly used BOD measurement. BOD creating substances can occur in either settleable or soluble forms. The maximum amount of BOD that can be present in discharge from a treatment system is established to prevent oxygen depletion in receiving water bodies.

Total Suspended Solids (TSS)

TSS includes both organic and inorganic particles that settle out of the water column under quiescent conditions. Releasing excess amounts of TSS into a receiving water body creates turbid conditions that can impede respiration and feeding functions of aquatic creatures, as well as cause the formation of "sludge banks."

"Wherever possible, emphasis should be placed on a "low impact" engineering approach. This not only avoids unnecessary expense but can enhance the natural processes involved in the use of wetlands. The design concept should be to have the system fit naturally into the landscape following the topography and minimizing straight dikes and 90° corners. If wetland habitat is a value, then islands with nooks and crannies should be liberally placed in the wetland surface."

[Gearheart et al., 1992]

Nitrogen

Nitrogen can exist in a variety of forms. Organic nitrogen is typically associated with wastewater solids or algae. Much of this nitrogen will undergo decomposition or mineralization within the system. Inorganic nitrogen, in the form of ammonia, nitrate, nitrite, or nitrogen gas is a result of biological nitrification and denitrification reactions. Although nitrogen removal is not a typical parameter included in a discharge permit, wetland design can provide sufficient oxygen, carbon and retention time to remove organic and inorganic nitrogen. Introducing excess nitrogen to a water body can lead to **eutrophic** conditions. Some forms of nitrogen can be toxic to aquatic life.

Eutrophic refers to water rich in nutrients and high in biological activity.

In order to effectively remove nitrogen through nitrification and dentrification, open water zones should be provided in the constructed wetland. Providing a series of vegetated and open water zones provides for the anaerobic and aerobic zones needed for nitrification of ammonia to nitrate, and dentrification of nitrate to nitrogen gas[2].

Phosphorous

Phosphorus is an essential element in the growth of algae and in excessive amounts can lead to noxious algal blooms. The primary mechanisms for removal of phosphorus in wetland systems are chemical precipitation and adsorption by the soil matrix. The degree of phosphorus removal in the wetland is dependent upon the amount of contact that the wastewater has with the soil matrix. Due to this limitation, free water surface wetlands will have less potential for phosphorus removal than subsurface flow systems. Both of these types of systems are described later in this chapter.

Once the wetland has been sized to remove the regulated pollutant, the designer must determine wetland characteristics. Some issues to consider are discussed below.

Hydrology describes the average behavior of the wastewater as it flows through the wetlands. Hydraulics refers to the physical mechanisms used to convey the water through the wetland.

Hydrology

Controlling the average behavior of wastewater as it flows through a wetland is key to its long-term success. Flow through a wetland more closely resembles plug-flow than completely mixed flow. Short-circuiting and dead pools need to be minimized in order more closely resemble plug-flow conditions. **Hydraulic residence times** are crucial design elements that assume uniform flow behavior.

Hydraulic residence time refers to the amount of time wastewater is in a wetland system. If the wastewater flows through the wetland too fast, then it may not be adequately treated.

Most treatment wetlands are designed to prevent stormwater runoff from entering the wetland, unless the intent is to treat stormwater runoff. This is achieved by locating the wetland in a highpoint and/or with the use of berms to route stormwater runoff away from the wetland. Flow characteristics through the wetland include:

[2] *Constructed Wetland Treatment of Municipal Wastewaters*, USEPA Office of Research and Development, Cincinnati, Ohio, EPA /625/R-99/010, September 2000.

- **Velocity** – this is controlled by selecting a bed slope that provides a sufficient hydraulic gradient through the wetland to achieve the desired velocity.
- **Detention Time** – the amount of time that it takes a unit of volume to travel from the inlet to the outlet of the wetland is determined by the size, depth, and travel path through the wetland.
- **Depth of Flow** – a design depth must be chosen to provide adequate storage and appropriate conditions for the wetland plants chosen.
- **Travel Path** – providing an appropriate length to width ratio will prevent short-circuiting through the system.
- **Water Balance** – the designer must determine the sources and sinks that will occur in the wetland. Groundwater influences are generally minimized by the use of liners. It is important to determine the contribution that precipitation and evapotranspiration will have on wetland hydrology.

Hydraulics

The wetland hydrology will determine many of the controls of the wetland hydraulics. Hydraulics refers to the physical mechanisms used to convey the water through the wetland. Important components of the hydraulic system include:

- **Conveyance System** – typically a pipe will be used to transport the wastewater from the primary treatment to the wetland.
- **Inlet Mechanism** – wastewater is introduced to the wetland cells by using slotted pipes at the head of the wetland cells, teed down the length of the cells, or a variety of other methods.
- **Depth Control** – various mechanisms are used to control water depth in the wetland. Swivel Tees or overflow weirs are commonly used.
- **Isolation Devices** – it is important to be able to provide flexibility for the flow path in order to allow wetland cells to be taken offline for maintenance. Splitter boxes are typically used to provide the ability to reroute the flow through the wetland.
- **Collection Device** – after the wastewater has flowed through the wetland it is collected for final discharge from the system. Typical collection mechanisms include drainage channels and buried slotted pipes.

Shape

The designer must develop a wetland shape that provides the surface area requirements and fits into the site topography. Often, existing lagoons are retrofitted to accommodate a wetland system. Providing appropriate length to width (aspect) ratios may also dictate the shape of the wetland. Aspect ratios as high as 10:1 are often recommended in order to prevent short-circuiting of the wastewater as it flows through the system.

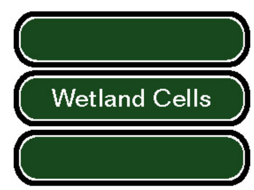
Hydrologic Issues

- Velocity
- Detention time
- Depth of flow
- Travel path
- Water balance

Hydraulic Issues

- Conveyance system
- Inlet mechanism
- Depth control
- Isolation devices
- Collection devices

Shape A



Shape B

Shape Variations

Typically engineered wetland systems, like Shape B, are rectangular and unnatural in shape. Natural shapes with curves and varied edges, like Shape A, allow for more biodiversity than their rectangular counterparts. The shape of the treatment cell does not impact its effectiveness, although it may impact construction costs.

Providing islands and irregular boundaries can enhance the habitat value of a wetland. However, because the construction of a wetland system is generally bid, the needed improvements must be well defined in order to enable the contractor to develop take off quantities. Typically, this forces a more rectangular wetland shape.

Soil

The wetland soil will provide the media for plant and microbial growth. Depending on the type of wetland designed, the designer may need to specify a particular mix of soil and gravel. The designer may specify that the soil include additives to encourage the growth of wetland plants. A geotechnical study should be performed to determine the suitability of the native soil to support a wetland system.

Plants

Wetlands can be planted, seeded, plugged or left to establish themselves. Designers must specify the type and introduction method that will be used in the wetland.

Ancillary Benefits

The designer can incorporate additional features into the wetland system that do not detract from the primary goal of wastewater treatment. Some of these benefits include aesthetic appeal, educational value, recreational outlets and habitat value. Interpretive centers can be incorporated into the wetland design to provide educational opportunities on such topics as energy conservation, wastewater treatment, wetland ecology, and pollution prevention. If the wetland designer wishes to incorporate these aspects into the wetland design, planning must include a safe means of public access.

Maintenance

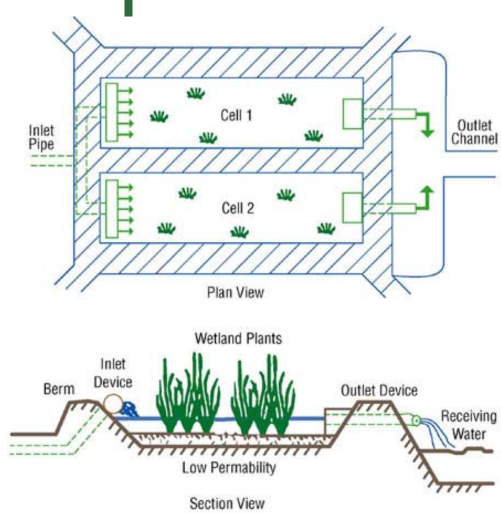
Wetlands will take several years to establish a mature ecosystem. In the design process it is important to determine what methods will be used to harvest vegetation once the litter layer becomes excessive. Potential methods include burning and physical harvesting of wetland biomass. Other maintenance issues include (1) clearing of clogged piping, (2) controlling mosquito and fly populations, and (3) managing nuisance wildlife (i.e. muskrats).

Free Water Surface Flow and Subsurface Flow Wetlands

Two general types of wetlands are typically constructed for wastewater treatment: free water surface flow (FWS) and subsurface flow (SF) wetlands.

In a FWS wetland, water is generally introduced above the ground surface, and flows through the wetlands at depths averaging less than 6 inches, ranging up to 12 inches (Figure 1). FWS wetlands may contain

"Wetlands for water quality are being constructed throughout North America at an accelerating rate. However, many wetland designs do not incorporate ancillary benefits to the extent possible. With thoughtful design, constructed wetlands can provide benefits beyond effective water treatment, such as wildlife enhancement and recreational opportunities. In fact, with the decline of the total area of natural wetlands, constructed treatment wetlands are a viable and cost-efficient way to compensate for the loss of productive wetland habitat."
(Kadlec and Knight 1996)

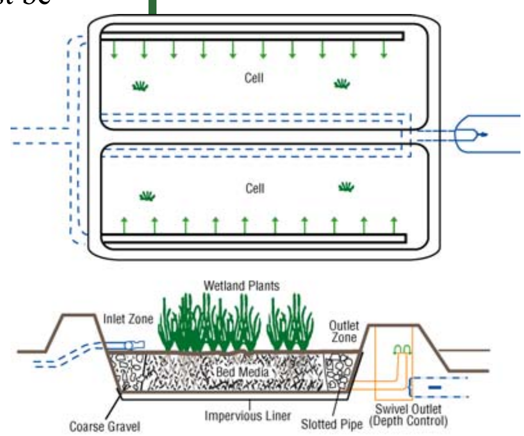


Plan and profile of a typical free water surface wetland.

islands that are at or above the typical water surface, and small, deeper areas, up to 8 feet. However, these deeper areas will not support wetland vegetation.

FWS wetlands are often divided into cells either by earthen berms, concrete, or wood to help direct flow and insure that maximum contact between water and wetland plants. Wetland plants can be established by seeding or transplanting. If a significant source of wetland seed exists nearby, and if the topsoil used in the treatment wetland contains enough propagules, it may be unnecessary to seed or plant the wetlands. Maintenance of a FWS wetland may include periodic burning of the vegetation in the treatment wetland, monitoring and adjusting the water surface elevation, keeping the inflow and outflow structures clear of debris, and sediment removal when necessary.

In a SF wetland, water is introduced into a gravel medium through a perforated pipe or other underground dispersal system. SF wetlands may contain up to 4 feet of gravel, and the water surface elevation is maintained just below the top surface of the gravel. Generally wetland plants must be planted into a SF wetland because the gravel substrate is often not conducive to seed germination and establishment. Maintenance of a SF wetland may include periodic burning of the vegetation in the treatment wetland, monitoring and adjusting the water surface elevation, keeping the inflow, outflow, and dispersion pipes clear of debris, and sediment removal when necessary. SF wetlands are often difficult to maintain because the underground pipes may be subject to clogging and the gravel surrounding the pipes may become clogged with sediment.



Plan and profile of a subsurface flow wetland.